APPLICATION OF COMPLEX INDICES FOR COTTON FIBER QUALITY CHARACTERIZATION

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Abstract

The purpose of the paper is to describe the complex evaluation of cotton fibre quality (cotton quality index U) statistical characteristics based on so called Bootstrap based idea. The results of HVI measurements are here input information. The core of Bootstrap is generations of artificial samples from proper distribution. In this work two methods are described. First method is based on the three parameter Weibull distribution and can be used if the primary measurements are at disposal. Second much rough method is based on the normal distribution and it is useful if the only mean values of all HVI properties are given. The second method is demonstrated on the real data of results of the crop study of 1997 and 1998, which includes 33 varieties of cottons.

Introduction

The quality of the textile fibers is dependent on the aims of evaluation:

- Fibre producers: quality means the achievement of required technological parameters (geometrical evenness, fineness, shrinkage, mechanical and physical parameters etc.).
- Textiles producers: quality means the ability to fulfill requirements of technologic operations and process ability (friction, surface properties, cohesion, selected mechanical and physical properties, and evenness).
- Consumers: fiber quality is hidden in the properties and comfort of fabrics (hand, wearing pleasance, thermal comfort, transport properties etc.).

Natural fibers: controlled changes of properties are very difficult (selection, breeding, gene manipulation) and therefore the quality is oriented to the process ability, yarns characteristics (especially strength) and mixing potential.

Chemical and synthetic fibers: by variation of fiber geometry (fineness, cross section profile, texturing) and spinning conditions (rate of production, drawing degree, temperature, forming conditions) is possible to change majority of properties markedly. The chemical modification is another way to change properties. The general definition of quality according to the aim of utilization can be here used for ranking and classification.

According to the general definition, the quality is characterized by several properties expressing the ability of a product to fulfill functions it was designed for. The degree of quality (complex criterion) is often expressed as utility value U (Militký 1980). Evidently, general quality of textiles is characterized by many of various utility properties R_i ($i = 1,\ldots m$). These are such properties that make it possible for the product to fulfill its function. Utility value $U \in <0, 1>$ aggregates then in some certain way partial quality properties (Militký 1980). When forming the aggregating function U from experimentally determined values of cotton fiber properties, the statistical character of the R_j quantities should be considered and the corresponding variance $D(U)$ should be also determined besides the U. One procedure for estimation of $E(U)$ and $D(U)$ based on Taylor series expansion is given in the paper (Militký 1980). The purpose of the paper is to use computer intensive Bootstrap based technique for description of the cotton fibre quality characteristic (cotton quality index U).

Cotton Fiber Quality

In 1907 an international group of cotton industry representatives recommended to establish uniform cotton standards to "eliminate price differences between markets and make the farmers more cognizant of the value of the value of their products". In response to requirements of standardization the cotton grade standards and cotton classification systems were elaborated and authorized by US Dept. of Agriculture.

The cotton classification is now system of standardized procedures for measuring of raw cotton properties (physical attributes) that affect quality of processing (spinning mainly) and quality of products (yarns). The classification system of US cottons is described on the net (http://www.cottonic.com/CottonClassification).

There exists a plenty of standard and HVI techniques for characterization of cotton fibers. It is known that there are some differences in the principles of measurements and the results of AFIS and HVI spectrum apparatus. The differences exist between measurements of fiber strengths based on the bundles concept or single fiber concept as well. Despite of these differences it is possible to specify basic cotton fiber properties having potential influence to the cotton yarn strength (Rasked 2002):

fiber length (expressed as upper half mean *UHM* [mm],
fiber length uniformity (expressed as uniformity index *UI* [%]),
fiber strength (as bundle strength *STR* [cN/tex]),
fiber elongation ant break (*EL* [%])
fiber fineness and maturity (expressed by micronaire reading (*MIC* [-]),
short fiber content (*SF* [%]),
trash content *TR* [%].

The importance of these properties is generally dependent on the spinning technology. The relative weight *b* of above listed properties (as importance percentages divided by 100 and then standardized - sum of weights should be one) are given in the Table 1.

Table 1. Contribution of cotton properties to the yarn strength

Property/weight	Rotor yarn	Ring yarn
UI [%]	0.20	0.22
MIC [-]	0.16	0.17
UHM [mm]	0.14	0.24
STR [g/tex]	0.28	0.22
EL [%]	0.09	0.06
SF [%]	0.06	0.06
TR [%]	0.07	0.03

The values in the Table I were derived from pie graphs presented in the work (Rasked 2002). The main problem with utilization of above-mentioned properties for quality characterization is multivariate character of information, various units and lack of transformation to the utility scale.

One of first attempts to create aggregated criterion of cotton fiber quality was **fiber quality index** (FQI) expressed by relation (Anonym 1983)

$$FQI = (fiber\ strength*length)/fineness \quad (1)$$

South India Textile Research Association proposed modified version in the form

$$FQI = (fiber\ strength*length*uniformity*maturity\ coefficient)/fineness$$

For HVI results is *FQI* expressed in the form

$$FQI = \frac{UHM * UI * STR}{MIC} \quad (2)$$

Some other criteria are based on the regression models connecting fiber properties with parameters characterized spinning ability or quality of yarn (characterized by yarn strength). The **spinning consistency index** (SCI) is connected with cotton HVI properties through regression model ((Anonym 1999))

$$SCI = -414.67 + 2.9 * STR + 49.1 * UHM + 4.74 * UI - 9.32 * MIC + .95 * Rd + 0.36 * b \quad (3)$$

where *Rd* is reflectance degree and *b* is yellowness of fiber. Based on the regression equation relating fiber properties with yarn strength the **premium discount index** (PDI) was derived. The PDI expressed in the standardized fiber parameters (Majundar et all**.** 2005) has the form

$$PDI = 22.15 * STR^{*} - 4.75 * EL^{*} - 4.37UHM^{*} + 11.9UI^{*} - 20.78 * SFC^{*} - 7.8 * MIC^{*} \quad (4)$$

where superscript (*) denotes the standardized variable (mean value subtraction and division by standard deviation). The **multiplicative analytic hierarchy process** (MIA) criterion can be expressed by relation (Majundar et all**.** 2005)

$$MIA = \frac{STR^{0.27} * EL^{0.039} * UHM^{0.291} * UI^{0.145}}{MIC^{0.11} * SFC^{0.145}} \quad (5)$$

In the book (Korickij 1983) so called **geometric properties index** (IG) was introduced. This index is based on LVI measured properties

$$IG = 0.1*L_m*UI*(1-SF/100)*MAT*(FI)^{-0.5} \quad (6)$$

where L_m is cotton fibers weighted mean length, *FI* is fiber fineness and *MAT* is maturity. For HVI measured properties can be *IG* expressed as

$$IGa = \frac{UHM * UI * (100 - SF)}{10000 * \sqrt{MIC}} \quad (7)$$

or

$$IG = \frac{UHM * UI * (100 - SF) * MAT}{1000000 * \sqrt{FI}} \quad (8)$$

The relation (7) is very rough because the micronaire is combination of fiber fineness and maturity. **Complex quality index (IK)** expressing the spinning ability of cottons is then defined as combination of IG and B with including of cotton fibers price C.

$$IK = A_4 * B * I_g{}^4 / C \quad (9)$$

where A_4 = 0.0108 for long staple cottons and A_4 = 0.0141 for medium staple cottons. These relations were derived from Russian cottons and LVI measurements.
The main problem with all above mentioned characteristics of cotton fiber quality are:

1. strong dependence on the units for individual cotton properties and methods for their evaluation,
2. utilization of dimensional parameters based on the limited amount of experimental data (from the past crops),
3. no inclusion of individual fiber properties importance for individual spinning technologies.
4. no possibility to change parameters for new crops without tedious experimentation
5. no defined ranges (limits) for quality indices.
6. no possibility to include the direction of some properties influence to quality indices dependent on their real values (case of micronaire).

Our approach based on the utility function concept is more general and be easily modified for the future (the properties of cottons are in dependence on time progressively changed in positive sense due to breeding and genetic manipulation)

Utility Value Concept

Evaluation of quality based on complex criterion (cotton quality index U) is closely related to the well-known problem of complex evaluation of variants (Černý M. et all 1980). For complex evaluation of variants, the ***X*** matrix of the (n x m) order is available containing for individual V_1,.....V_n variants (***X*** matrix rows) the values of selected R_1,.......R_m characteristics (***X*** matrix columns).

The x_{ij} element of the matrix thus expresses the value of the j - th characteristic of R_j for the i-th variant of V_i. The aim is to sort individual variants in the order of their importance. In economics several different methods are used in this field and most of them are based on preferential relations (Černý M. et all 1980). A special technique is the so called "useful effect method" or "base variant method". Base variant practically represents an ideal state where individual characteristics get optimum values.

By means of o_j (j = 1,...m) values for individual characteristics of a base variant, dimensionless standard quantities u_{ij} are calculated. If the increase of the R_j characteristic is accompanied by the increase of quality, the standard quantities are calculated according to the relation

$$u_{ij} = \min(\frac{x_{ij}}{o_j},1) \qquad (10)$$

In opposite case, the dividend and the divisor are interchanged. As $U(R) = U(u)$ is aggregating function a suitable weighted average is used.

Modification of this approach for expressing of textiles quality is shown in the work (Militký 1980). The procedure for prediction of cotton fibers quality from point of view of the yarn strength is described in sequel.

Let we have K utility properties $R_1 ,...,R_K$ (cotton fiber properties selected in the Table I). Based on the direct or indirect measurements it is possible to obtain some quality characteristics $x_1 ,...,x_K$ (mean value, variance, quantiles etc.). These characteristics represent utility properties. Functional transformation of quality characteristics (based often on the psycho physical laws) lead to partial utility functions

$$u_i = f(x_i, L, H) \qquad (11)$$

where L is value of characteristic for just non acceptable cotton ($u_i = 0.01$) and H is value of characteristic for just fully acceptable product ($u_i = 1$). Cotton quality index U i.e. utility value is weighted average of u_i with weights b_i

$$U = ave(u_i, b_i) \qquad (12)$$

Weight b_i corresponds to the importance of given utility property and is closely connected with area of cotton application. The weighted geometric mean used as average has following advantages:

- For zero value of u_i is also $U = 0$. This means that combinations of other utility properties cannot replace non-acceptable utility property.
- Geometric mean is for not constant u_i always lower that arithmetic mean. This reflects evaluation based on the concept that the values of utility properties close to unsatisfactory cottons are more important for expressing the quality than those close to optimum cotton.

For the cases of cotton fibers quality are utility properties and weights already selected (see. Table I).
For aggregation the weighted geometric mean can be used and therefore the preferential functions $u(x_i)$ have to be proposed only. Partial utility function is in fact psychophysical variable expressing the sensation of quality induced by (measured) characteristic of cotton property. The computation of preferential functions is dependent on the measurement scale and property type.

Ordinal characteristics - in this type of scale, classification has been introduced, but differences are not quantified. Grades are awarded by the comparison with etalons.
Cardinal characteristics - are usually expressed in physical units. There are two types of cardinal characteristics.
One-side bounded characteristics are those where after the H_j value has been exceeded utility does not change any more (fiber strength, length, etc.). After standardization the partial utility function is computed e.g. by using Harrington preference function.

Two-sides bounded characteristics are those where on both sides from "the optimum" partial utility decreases. (e.g. fiber micronaire).

The nonlinear transformation to preference functions for cardinal utility values is given in the work (Militký 1980). For expressing quality of cotton fibers it is sufficient to replace standardization and nonlinear transformation to the partial utility function by the piecewise linear transformation.

For one side bounded properties quality is monotone increasing or decreasing function of quality characteristic x and therefore the piecewise linear transformation has form shown on the Fig. 1. For the case of LB (lower is better) properties were limits selected according to the known ranges published e.g. in (Militký 1980).

Trash content TR [%]	$L = 6$	$H = 2$
Short fibre content SF [%]	$L = 18$	$H = 6$

For the case UB (upper is better) properties were limits selected according to the known ranges published e.g. in (Militký 1980)

Strength HVI STR [g/tex]	$L = 23$	$H = 31$
Length UHM [mm]	$L = 25$	$H = 32$
Uniformity index UI [%]	$L = 77$	$H = 85$
Elongation EL [%]	$L = 5$	$H = 7.7$

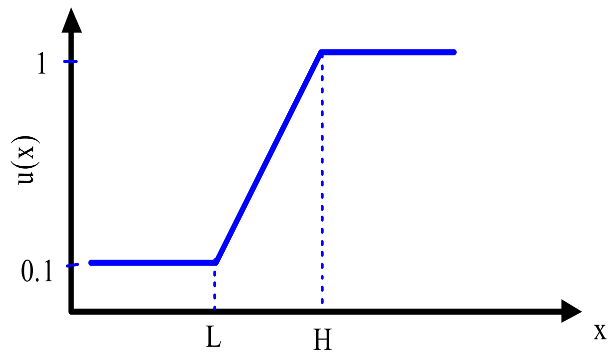


Figure 1 Transformation for one side bounded cotton properties (*L* is lower limit and *H* is upper limit)

For two side bounded properties quality is monotone decreasing function of property value x on both sides from optimal (constant) region and therefore has the piecewise linear transformation form shown on the Fig. 2

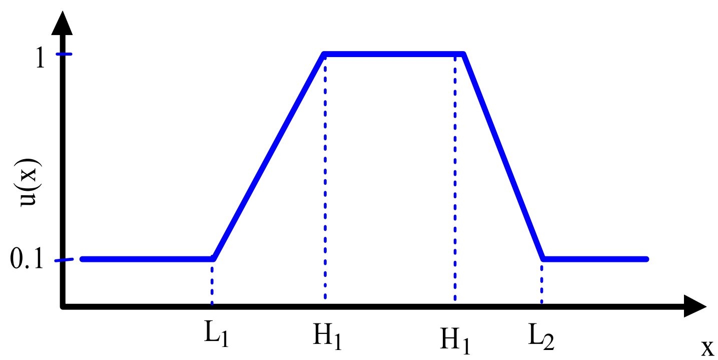


Figure 2 Transformation for two side bounded cotton properties (L1, L2 are lower limits and H1, H2 are upper limits)

For this case were limits selected according to the known ranges published e.g. in (Militký 1980)

Micronaire MIC [-]	$L_1 = 3.4,\ H_1 = 3.7$	$L_2 = 5,\ H_2 = 4.2$

The weighted geometrical average U characterizing cotton fibers quality i.e. cotton quality index is then simply calculated by the relation

$$U = \exp\left(\sum_{j=1}^{m} b_j * \ln(u_j)\right) \qquad (13)$$

When forming the aggregating function U from experimentally determined values of individual utility properties, the statistical character of the x_j quantities should be considered and the corresponding variance $D(U)$ should be also determined. Program *QCOTTON* written in MATLAB is based on the above-proposed procedure.

Bootstrap simulation

The Bootstrap type technique described in (Meloun, Militký 2011) has been applied for computation of the statistical characteristics of cotton quality index. This technique is based on the assumption that for each utility property R_j the mean value x_j and variance s^2_j are determined by standard treatment of the measured data. The procedure of the statistical characteristics of cotton quality index U estimation is divided to the following parts:

I. Generation of $x^{(k)}_j$ ($j=1,....,m$) values having normal distribution with mean values x_{mj} and variances s^2_j. The pseudorandom number generator built in MATLAB is used.
II. Calculation of the cotton quality index $U^{(k)}$ using the relation (12).
III. The steps I and II are repeated for $k=1,....,n$ (usually $n = 600$ is chosen).
IV. Construction of a histogram from the values $U^{(k)}$ (k=1,.....n) and computation of the estimators of $E(U)$, $D(U)$.

The core of Bootstrap is generations of artificial samples from proper distribution.
First method is based on the three parameter Weibull distribution and can be used if the primary measurements are at disposal. Distribution function of three parameter Weibull distribution this distribution has simple form for property
$FC = x_j$

$$F(FC) = 1 - \exp\left[-\left(\frac{FC - A}{B}\right)^C\right] \quad (14)$$

Here A is lowest value of property, B is scale parameter and C is shape parameter. For quick and rough parameter estimates of three parameter Weibull models the moment based method can be used. The main idea of this method is very simple. Based on the selected 3 sample moments and corresponding theoretical moments for the 3 nonlinear equations can be created. Their complexity is based on the suitable selection of moments.
The Weibull type moments can be used for for estimation of the parameters in three parameter Weibull distribution (Cran 1988). Shape parameter C can be estimated from relation

$$C = \frac{\ln(2)}{\ln(m_1 - m_2) - \ln(m_2 - m_4)} \quad (15)$$

For estimation of the lower limiting strength A is valid

$$A = \frac{m_1 \; m_4 - m_2^2}{m_1 + m_4 - 2 \; m_2} \quad (16)$$

and estimate of scale parameter B is in the form

$$B = \frac{m_1 - A}{\Gamma(1 + 1/C)} \quad (17)$$

where Γ(x) is Gamma function. In these relations m_r are special, so-called Weibull sample moments defined as

$$m_r = \sum_{i=0}^{N-1} (1 - i/N)^r \left[FC_{(i+1)} - FC_{(i)} \right] \quad (18)$$

For i = 0 is formally $FC_{(0)} = 0$. The so-called order statistics $FC_{(1)} < FC_{(2)} < ... < FC_{(N)}$ (which are the sample values arranged in the increasing order) are here used. This very simple technique can be used for the estimation of parameters in three parameter Weibull models.

Second method is based on the normal distribution and it is useful if the only mean values x_{Mj} of all HVI properties are given. Here it is necessary to have external information about variability of measurements.

Variability of HVI Data based on Single Tests (Drieling 2005) expressed as coefficient of variation is given in the table 2.

Table 2. Variability of HVI Data

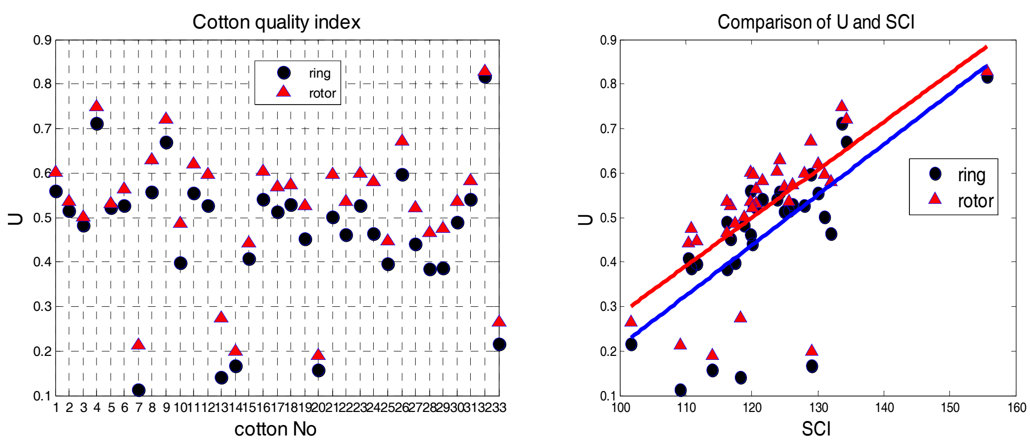
Property	Standard Deviation	Coefficient of Variation (CV%)
Micronaire	0,09	2,3 %
Strength HVICCS, g/tex	1,4	5,0 %
Length (UHML), inch	0,017	1,5 %
Length Uniformity	0,79	1,0 %
Color Rd	1,1	1,5 %
Color +b	0,40	4,0 %
Not included due to the high variability of the data: e.g. Trash, Elongation, SFI		

For not included properties CV = 6 % is selected

The normal distribution N(x_{Mj} , s_j) is then used for generation of the Bootstrap samples. For generation of simulated samples random numbers N(0,1) generated by random number generator are used. These values are transformed to the individual variables x_j by relation $x_j = x_{Mj} (1+CV_j/100)$ where CV_j are variation coefficients given in table II. As robust characteristics of total mean from all simulated samples E(U) the median value is used and as interval covering 95% of Bootstrap sample means the 2. 5 and 97.5 % all sample quantiles are calculated.

<u>Experimental part</u>

The results of the crop study of 1997 and 1998, which includes 33 sets of cottons (Majundar et all**.** 2005) were used for comparison of *U* with some other cotton quality indices. For different cotton varieties the International Textile Center (USA) evaluated the all characteristics required to computation of cotton quality index *U* excluding thrash content (in evaluation of *U* the value *TR = 2* was selected). The cotton quality index U for all cotton varieties are given in the Fig. 3a). The best correlation exists between *U* and *SCI* (see. Fig. 3b)). Corresponding correlation coefficient for ring yarn is *r = 0.692* and for rotor yarn is *r = 0.693*. Other correlations are highly significant as well. In each cases are visible the outlying points with very low values of *U*. Main reason of this deviations are higher low limits for *UHM* (25 mm) and low higher limit for *MIC* (5) used for computation of *U*.



a) b)

Figure 3 a) Computed cotton quality indices, b) Comparison of U and MIA

Histogram of cotton quality indices U (for ring yarns) estimated from Bootstrap samples (second method) is shown in the fig. 4

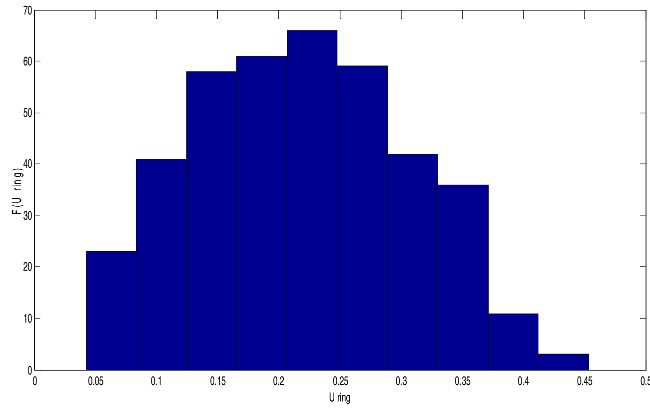


Figure 4 Histogram of U from Bootstrap samples,

The corresponding interval covering 95% of Bootstrap sample means is shown in the fig. 5

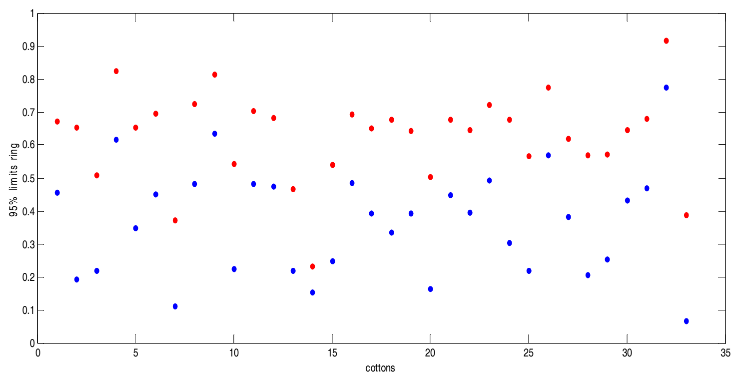


Figure 5 Histogram of U from Bootstrap samples

The differences between mean values and medians of cotton quality indices U (for ring yarns) estimated from Bootstrap samples (second method) is shown in the fig. 6

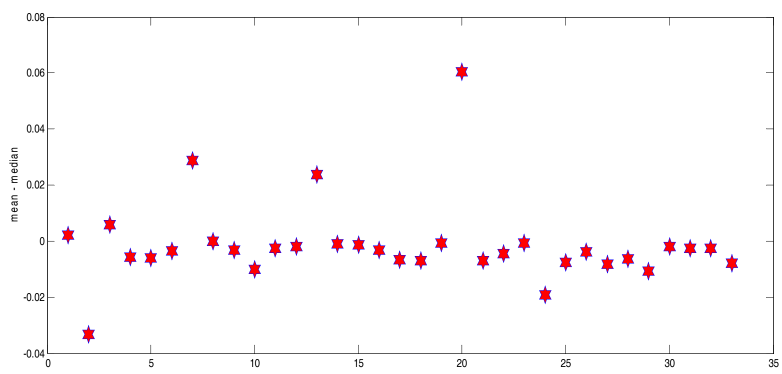


Figure 6 The differences between mean values and medians of cotton quality indexes U

It is visible that the both estimators are relatively close for majority of cotton varieties.

Summary

Described procedure for evaluation of cotton quality index *U* can be very simply modified for other selected properties or other set of weights. This is important for future cotton varieties. Based on preliminary results it will be probably necessary to solve problems with some cotton varieties having small micronaire due to fineness and relatively high strength. For these cases will be necessary to add restriction to the L_1 and H_1. The Bootstrap based approach is useful for estimation of variability of U.

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